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BY
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STUDIES ON THE IRRIGATION OF CITRUS GROVES[1]

By EDWARD E. THOMAS

There are many complex and as yet unsolved problems connected with irrigation in semiarid regions. As will be shown later, the method employed in the application of water may be the deciding factor between success and failure of crops. In order to obtain the best results, a careful study of the water requirements of the crops grown and of the best method of applying the water should be made.

Similar soils under different atmospheric conditions may require variations in the irrigation practice. The rates of transpiration by the crop and evaporation from the surface of the soil are probably much greater in the interior sections of California than in the coastal regions, because the temperature and aridity of the former are higher than of the latter. These factors may determine, in considerable measure, the times of application and the amount of water needed.

Wide differences occur in the soil conditions in different sections. The method of irrigation best suited to heavy soils may differ from that of light sandy soils, for the reason that the former type tends to restrict the movement of water, while the latter permits freer percolation and in turn gives up the water more readily.

The content of colloidal material may vary in soils which have the same wilting coefficient as determined by the centrifuge method. A soil which contains an appreciable amount of colloidal material will swell or expand upon being wetted. This swelling tends to retard the movement of water and also reduces aeration. A difference in the swelling may be brought about not only by a difference in the amount of colloid present, but also by a difference in the nature of the colloid. Consequently, two soils, although they may have the same water holding capacity as judged by the centrifuge method, may act in an entirely different manner when wetted.

Generally speaking, the practice of irrigation in the citrus groves of California has followed certain arbitrary rules, especially in regard to the frequency of application and the amount of water applied. There is very little definite knowledge concerning the economy of the methods in use.

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[1] Paper No. 81, University of California Citrus Experiment Station and Graduate School of Tropical Agriculture, Riverside, California.

The fact that crop growth is stimulated by the application of moderate amounts of water, seems to have led some citrus growers into the error of applying excessive amounts. Instances are known where as much as sixty acre-inches per acre have been applied in one irrigation season. In such cases, the naturally dry portion of the year is effectively converted into a wet season, so far as the soil is concerned, since the annual rainfall is only ten to fifteen inches, which falls mainly in the winter months. Excessive irrigation is most prevalent in sections where the water is drawn from readily available supplies, such as rivers.

There are instances where water has been applied early in the spring, before the usual irrigation season, with a view to "storing up" moisture in the soil for use during the dry season. Later, whenever irrigation water is available, excessive amounts may again be applied, regardless of the moisture content of the soil at the time. Many citrus groves located on heavy soils have been heavily irrigated as frequently as every ten days to two weeks during the spring and early part of the summer.

Citrus trees are more sensitive to an excess of moisture than some other crops. For this reason the supply of soil moisture in citrus groves should be carefully controlled.

The methods of distributing the water have not been given adequate consideration. At present, the irrigation furrows are often from 500 to 800 feet in length and one citrus grove has been under observation which is irrigated from furrows 1380 feet in length. As will be shown below, a uniform distribution of irrigation water is impossible with the use of furrows of such length.

An interesting experiment to test the effect of various moisture conditions on the growth of lemon trees was conducted with a loam soil of the Limoneira Ranch Company, Santa Paula, California, by Fowler and Lipman.[2] By growing young lemon trees in cylinders in which the moisture content was varied, they determined the percentage of moisture at which the soil must be kept in order to produce the best growth. They found that the growth of the trees was retarded when the moisture content was either above or below the optimum. The optimum, however, appears to be not a fixed point, but rather covers a considerable range.

Not all of the moisture in a soil can be absorbed by plants. A part of it is unavailable, the amount of which varies with the soil

[2] "Optimum Moisture Conditions for Young Lemon Trees on a Loam Soil." By L. W. Fowler and C. B. Lipman, Univ. of California Publications in Agricultural Sciences, Vol. 3, No. 2, pp. 25–36, September, 1917.

type. The amount of unavailable moisture in a heavy soil is sufficient to saturate a light, sandy soil. It is important, therefore, to distinguish between the available and unavailable moisture in a soil.

Briggs and Shantz state that,[3] "in connection with the study of the moisture requirements of plants in semiarid regions it is necessary to be able to determine quickly the soil-moisture content at the wilting point. This constitutes the datum from which the moisture available for growth can be calculated and without which field determinations of soil moisture are of little value."

The unavailable water in soils is now commonly determined by the use of the moisture-equivalent centrifuge. The data thus obtained are referred to as "wilting coefficients." The wilting coefficient is supposed to indicate the moisture content of the soil when a plant becomes permanently wilted. By the permanent wilting of the plant, is meant a condition from which it cannot regain its turgor when surrounded by a saturated atmosphere, unless water be added to the soil.

As previously intimated, the determination of the so-called wilting coefficient may not always give data by which the water-absorbing and water-retaining power of soils derived from entirely different sources can be measured accurately. Such data, however, probably afford information of considerable value in comparing soils of a similar type.

The present paper is based on experiments which were conducted for two seasons in certain citrus groves located on a heavy type of soil. The groves studied are located in the Whittier, East Whittier and La Habra sections of Los Angeles and Orange counties. While the results obtained and the conclusions drawn may not apply equally to other types of soil, it is believed that some of the practical lessons taught by these studies are widely applicable, and sufficiently general to warrant publication.

This investigation was conducted during the irrigation seasons of 1916 and 1917. The soils studied were all of the same general type, having a wilting coefficient of from 9 to 19 per cent, with an average of 14 per cent.

Four points have been investigated in this work: (1) the amount of water in the soil at the upper and lower ends of long furrows; (2) the appearance and productiveness of the trees growing at the upper and lower ends of long furrows; (3) the amount of available

[3] "The Wilting Coefficient of different plants and its indirect determination." By Lyman J. Briggs and H. L. Shantz. Bureau of Plant Industry, Bull. No. 230, p. 8, February, 1912.

moisture[4] in the soil when the water was applied at intervals of 30, 45 and 60 days; and (4) the effect of deep and shallow cultivation on the water-absorbing power of the soil.

Altogether, twenty different groves have been studied. The results obtained with only seven of these, chosen to represent the districts in question, will be presented at present.[5]

The same general course of procedure was followed in each grove. Samples of soil were taken at regular intervals from a given plot and a determination was made of the total moisture content in each foot to a depth of four feet and, in some instances, to a depth of six or eight feet.

The wilting coefficient of samples representing each foot of the plots studied was determined by Mr. C. A. Jensen, formerly of the United States Department of Agriculture, to whom acknowledgement and thanks are extended.

I. *Comparison of the amount of water in the soil at the upper and lower ends of long furrows.*

In the grove chosen to show the effect of the length of furrow on the content of water in the soil, the furrows were 812 feet long with a fall of sixteen feet. Soil-moisture determinations were made on two plots in this grove during the 1917 irrigation season. The wilting coefficient of the soil to a depth of eight feet, is given in table I.

TABLE I

THE WILTING COEFFICIENT OF PLOTS A AND B, GROVE 1

Plot	1st ft.	2d ft.	3d ft.	4th ft.	5th ft.	6th ft.	7th ft.	8th ft.
A[1]	16.90%	17.15%	17.30%	16.90%	16.75%	16.75%	18.30%	15.20%
B[2]	16.90%	17.20%	16.90%	18.80%	19.00%	17.60%	16.80%	16.60%

[1]Situated at the upper end of the irrigation furrows.
[2]Situated near the lower end of the irrigation furrows.

As is common in irrigation practice in certain localities, the owner of this grove irrigates whenever he considers it necessary rather than at any stated interval. During the season of 1917 four irrigations were applied at intervals of thirty days, followed by three additional irrigations at intervals of 25, 37 and 41 days, respectively,

[4] The term "available moisture," as used in this paper, signifies the amount of moisture that is in excess of the amount of moisture represented by the wilting coefficient.

[5] See a previous paper by the writer, "Irrigation Studies at Whittier." The California Citrograph, January-February, 1917.

making a total of seven applications for the season. The first application was made on April 10 and the last on October 23. A total of 18.5 acre-inches of water was applied per acre.

When we study the data showing the moisture found in the two plots of this grove (table II) the one (A) located from twenty-two to sixty-two feet from the point of distribution, and the other (B) located 621 to 661 feet from the distributing line, we find that instead of the water being evenly distributed, the soil of plot B contained much less moisture than that of plot A. Since all of the water was distributed from the same pipe line, it was not possible to determine the amount of the water that was actually delivered to each plot.

The data in table II shows that the subsoil in plot A also contained much more moisture than did the subsoil in plot B. Since the roots of citrus trees seldom penetrate below a depth of four feet in this type of soil, a considerable part of the water applied to plot A certainly penetrated below the reach of the roots and, therefore, did not benefit the trees. Soluble plant food must also have been leached below the reach of the roots of the trees.

These data indicate that, under the present system of furrow irrigation, a uniform distribution of water throughout a grove cannot be accomplished with the use of long furrows. With this method of application, a portion of the water that is applied must inevitably be wasted, because of too deep penetration near the upper end of the furrows. In sections where the water is obtained from wells or expensive irrigation systems, this waste adds materially to the operating expenses of the grove. On account of leaching, soluble plant food is carried below the root zone of the trees, and increases the expense for fertilizers. As will be shown later, excessive irrigation may injure orange trees.

These faults might be corrected by increasing the number of distributing lines. The length of the furrows should not exceed 250 to 300 feet.

A portion of the expense incident to the installation of extra pipe lines would be offset at once by the reduction in the amount of water necessary to be applied, and, as shown below, the productivity of the trees would be increased.

TABLE II

Percentage of Available Moisture in Grove 1*

Depth in ft.	5/9	5/16	5/29	6/9	6/19	6/25	7/12	8/1	8/13	8/28	9/6	9/20	10/5	10/20
Plot A														
1st	−1.19	12.23	8.34	9.12	7.94	7.55	3.18	8.04	.53	1.93	9.24	7.06	12.44	3.87
2d	.05	13.47	9.80	8.78	7.17	8.86	6.57	11.09	3.85	8.26	9.31	9.46	12.99	9.94
3d	− .64	11.98	9.58	10.37	9.56	9.19	8.56	9.82	6.78	8.52	7.06	9.00	10.73	8.90
4th	− .13	11.10	8.53	9.45	10.65	10.53	6.05	8.34	8.52	8.82	8.27	9.02	11.32	9.10
5th	....	....	....	....	....	12.33	7.46	8.87	6.04	8.04	8.62	8.91	11.37	6.71
6th	....	....	....	....	....	11.53	6.58	10.23	5.10	9.86	10.10	8.25	10.26	7.83
7th	....	....	....	....	....	9.23	6.80	9.39	4.54	7.76	6.75	6.24	7.84	6.76
8th	....	....	....	....	....	11.11	8.39	10.50	9.21	10.37	9.20	8.71	11.80	10.51
Plot B														
1st	−6.43	14.20	8.36	5.52	3.71	8.85	.27	2.23	1.05	−1.05	6.14	−2.17	3.18	−3.41
2d	−4.70	10.60	7.62	5.44	7.05	6.22	− .22	2.47	1.79	− .11	3.92	− .96	3.94	−1.99
3d	−5.27	6.44	6.30	4.79	6.30	6.57	−1.67	1.52	.94	.61	1.85	−2.29	3.87	−1.50
4th	−6.52	5.10	4.61	3.82	5.28	4.05	− .88	1.93	1.16	1.70	5.68	−2.42	1.12	−2.49
5th	....	....	....	....	....	4.44	.09	2.44	2.81	2.39	7.51	−2.47	− .57	−2.60
6th	....	....	....	....	....	4.15	2.66	4.18	3.43	2.91	6.40	2.99	1.32	2.06
7th	....	....	....	....	....	4.70	2.16	3.04	3.91	3.62	5.34	4.29	3.83	4.51
8th	....	....	....	....	....	7.20	4.57	5.85	4.46	5.08	5.80	4.83	4.51	3.94

*The minus sign indicates soil moisture below the wilting coefficient.

II. *A comparison of the appearance and productiveness of trees at the upper and lower ends of long furrows.*

Two plots, K and L, (grove 2) are chosen to illustrate the effects of excessive irrigation on the appearance and productivity of the trees. This grove was irrigated from four distributing lines and plot K was located at the lower end of the furrows in an upper block of trees, while plot L was located just across a distributing pipe line from plot K at the upper end of the furrows in the second block of trees. Each plot consisted of nine orange trees. Plot K being adjacent to plot L, it is believed that the soil and climatic conditions in the two plots were similar in all respects.

The entire grove of sixty-seven acres was given the same kind of cultivation and fertilization, and it was irrigated throughout at thirty-day intervals, beginning the latter part of April.

The amount of water delivered to plots K and L was very different, as may be appreciated when their location is considered. Plot K was located at the lower end of irrigation furrows 248 feet in length, and plot L was located just across a distributing pipe line from plot K at the upper end of furrows 528 feet long. The entire section in which plot K was situated received an average of 2.43 acre-inches of water per acre at each irrigation, but as the experimental plot was located at the lower end of the irrigation furrows, the amount of water actually delivered to it must have been below the average for the plot. The section in which plot L was located received an average of 4.28 acre-inches at each irrigation. Since plot L was located at the upper end of the irrigation furrows, it must have received more water than the average for the section.

The difference in the appearance of the trees in different parts of the grove was very noticeable. All of the trees in plot K, the lightly irrigated plot, were in fine condition. They bore an abundance of normal green leaves and, without exception, produced a good crop of fruit. The trees in plot L, on the other hand, were in poor condition. Many of the leaves dropped prematurely and a large percentage of those remaining on the tree were yellow. The trees appeared to be suffering from a lack of nourishment and the crop of fruit was light.

A careful record of the amount of fruit produced on plots K and L was kept in 1917. It was found that the nine trees in plot K which received the smaller amount of water produced fifty-five boxes of fruit, while those in plot L yielded twenty-four boxes.

TABLE III

Percentage of Available Moisture in Plots K and L, Grove 2*

Plot K

Depth in ft.	4/20/17	5/5	5/14	5/22	6/1	6/13	6/22	7/7	7/17	7/24	8/4	8/13	8/23	9/5	9/14	9/22	10/5	10/15	10/22
1st	1.25	5.71	3.78	2.20	4.97	.28	–.28	–4.20	–1.33	–1.30	–.35	–1.68	–3.73	–2.02	–3.89	–5.07	–.78	–3.48	–4.61
2d	3.13	2.72	2.91	6.02	2.73	3.27	4.13	–1.42	.08	2.06	–.88	–.45	–1.81	–1.33	–.56	–1.94	–.27	–2.42	–2.37
3d	4.58	5.03	.45	5.22	.50	3.64	3.26	.04	–.73	4.01	–1.80	–.71	–.95	–3.20	–.73	–2.29	–1.05	–1.32	–2.39
4th	5.00	5.51	.38	4.02	3.25	3.29	2.58	–1.69	2.41	5.27	–.80	.59	1.82	.32	2.88	2.05	1.30	2.39	1.51
5th	....	....	....	....	....	....	5.94	1.16	3.23	2.63	.13	2.85	5.34	–.49	....	....	....	....	....
6th	....	....	....	....	....	....	4.75	.29	4.32	1.49	1.95	2.88	2.94	.65	....	....	....	....	....
7th	....	....	....	....	....	....	5.73	1.36	4.43	3.18	3.27	2.69	3.63	1.60	....	....	....	....	....

Plot L

Depth in ft.	4/20/17	5/5	5/14	5/22	6/1	6/13	6/22	7/7	7/17	7/24	8/4	8/13	8/23	9/5	9/14	9/22	10/5	10/15	10/22
1st	2.12	6.90	5.15	7.72	9.59	4.53	2.53	4.48	3.80	3.21	5.50	4.71	2.33	1.68	4.52	2.55	1.92	5.05	3.18
2d	5.08	9.95	5.20	7.33	9.27	6.90	6.55	7.86	6.18	6.44	7.32	7.46	5.04	4.29	7.37	6.93	4.86	7.40	6.40
3d	5.98	8.99	7.38	9.50	11.29	8.11	8.45	9.80	6.89	8.87	8.45	8.77	7.94	7.15	9.24	8.28	7.69	8.36	8.46
4th	7.07	8.17	6.34	8.09	12.60	10.65	8.26	8.40	10.77	12.76	10.80	9.32	8.12	7.66	9.93	6.65	7.61	10.40	9.51
5th	....	....	....	....	....	....	6.98	5.02	7.04	6.09	5.22	6.77	6.89	4.21	....	....	....	....	....
6th	....	....	....	....	....	....	7.41	5.43	6.38	6.06	4.74	6.31	6.75	3.77	....	....	....	....	....
7th	....	....	....	....	....	....	6.34	4.03	5.83	5.97	4.89	7.09	4.62	6.50	....	....	....	....	....

*The minus sign indicates soil moisture below the wilting coefficient.

Thus the trees in the adjoining plots K and L, with the same care and other conditions, with the exception of the amount of water delivered to them, were totally unlike in appearance and production. (The available moisture in plots K and L, Grove 2, is given in table III.)

It seems safe to conclude from the facts above presented, that the trees at the upper end of the long irrigation furrows received too much water. The more or less constantly water-logged condition of the soil in this case must have interfered with its proper aeration and also must have hindered normal root development.

III. *A comparison of the amount of available moisture in the soil when irrigations were applied at intervals of 30, 45 and 60 days.*

Whenever possible, irrigation practices should be so arranged that the water may be applied to the soil at the time when needed. The time of application, as well as the amount of water applied, should be controlled by soil moisture tests. While this means of irrigation control may be difficult of execution where the water is obtained from irrigation companies that use the present system of water distribution, it is possible to change the irrigation interval, and this should be done wherever the prevailing system is unduly faulty. It, therefore, becomes important to know whether the interval now in use in a given case is best suited to the soil type in question. Most of the groves in the district under consideration are irrigated every thirty days.

As a means of studying this question a comparison of the available moisture was made in groves that were irrigated at intervals of 30, 45 and 60 days.

Two adjacent groves were studied, one of which, grove 3, was irrigated at intervals of thirty days and the other, grove 4, at intervals of sixty days. These two groves were under the same management and, with the exception of the interval between irrigations, were given the same cultural treatment.

Grove 4 received an average of 5.7 acre-inches of water per acre every sixty days, which provides for a lesser amount of water for the season as a whole, than was applied to grove 3, which received an average of 4.28 acre-inches of water per acre every thirty days. Comparisons of the available moisture between plot C (grove 3) and plot G (grove 4) are shown in table IV. The wilting coefficients of these two soils are as follows:

	1st ft.	2d ft.	3d ft.	4th ft.
Grove 3, plot C	14.4%	15.2%	14.9%	14.4%
Grove 4, plot G	13.6%	14.7%	19.9%	14.5%

TABLE IV

PERCENTAGE OF AVAILABLE MOISTURE IN PLOT C, GROVE 3, AND PLOT G, GROVE 4*

PLOT C

Depth in ft.	4/20/17	5/5	5/14	5/22	6/1	6/13	6/22	7/7	7/17	7/24	8/4	8/13	8/23	9/5	9/14	9/22	10/5	10/15	10/22
1st..........	.32	6.53	3.81	4.02	6.79	.52	−2.47	4.63	−.93	−2.85	5.47	.72	3.12	6.21	2.68	−3.09	6.00	2.68	−2.90
2d...........	−.48	−1.48	−.58	1.00	1.94	−2.99	−1.49	2.85	−.97	−.92	5.17	−.97	1.93	2.35	3.26	.07	2.95	2.85	.29
3d...........	−.02	−.38	−1.12	.30	2.64	−4.60	−.18	.32	−.07	.27	1.17	−2.82	2.01	.05	1.89	2.45	.25	1.50	1.18
4th..........	−.12	.16	.51	2.20	4.30	−2.89	−.52	1.60	−.55	.52	−1.90	−3.17	2.54	−2.10	1.43	1.39	−.77	1.65	1.73

PLOT G

Depth in ft.	5/14/17	5/22	6/9	6/29	7/11	7/24	8/2	8/13	9/6	9/19	10/4	10/16	10/25
1st..........	6.40	4.52	1.73	−.53	2.90	.03	−2.94	−4.19	2.92	−1.02	−1.10	−1.03	−2.40
2d...........	7.39	7.79	4.68	2.81	4.12	2.26	−.73	−1.57	2.85	2.95	1.44	.46	.52
3d...........	7.63	7.93	4.45	3.62	3.99	2.66	−.02	.76	3.85	.54	.21	1.51	.24
4th..........	8.04	7.71	5.67	4.11	3.63	3.77	2.62	3.11	5.91	1.42	.94	.80	1.07

*The minus sign indicates soil moisture below the wilting coefficient.

The data show that plot G, grove 4, to which the water was applied at sixty-day irrigation intervals, contained as much available moisture as plot C, grove 3, which received a greater amount of water during the season, but applied at thirty-day intervals. A comparison of the trees in the two groves showed that, on the whole, the trees in the grove irrigated at sixty-day intervals were in better condition than those in the grove irrigated at thirty-day intervals.

Studies were also made on another grove (5). This grove was divided into nine plots, A to I inclusive. During the 1917 irrigation season, plots A and E were irrigated every sixty days; B, C, F and G every thirty days; and D, H and I every forty-five days. At each irrigation, plots A, B, E and F received an average of four acre-inches per acre; plots C and G an average of two acre-inches per acre; plots D and H an average of three acre-inches per acre; and plot I an average of six acre-inches per acre. Thus, plots A, C, D, E, G and H received the same amount of water during the season, while plots B, F and I received twice that amount. In this grove the irrigation furrows were 250 feet in length and the plots were all located between forty and sixty feet from the distributing pipe line.

The wilting coefficients in the nine plots of grove 5 are given in table V. A study of these data shows that the soil to a depth of eight feet, is quite uniform in all of the plots.

TABLE V

THE WILTING COEFFICIENT IN THE PLOTS IN GROVE 5

Plot	1st ft.	2d ft.	3d ft.	4th ft.	5th ft.	6th ft.	7th ft.	8th ft.
A	14.06%	13.5%	12.5%	11.0%	12.65%	14.9%	13.8%	14.24%
B	14.9	14.1	14.3	14.1	15.3	16.15	14.1	12.2
C	15.2	14.9	15.0	15.3	15.5	14.6	13.5	12.7
D	14.1	14.6	13.4	13.3	13.85	13.6	13.75	12.45
E	14.6	15.1	14.9	15.3	15.05	14.5	13.6	13.15
F	13.0	12.6	9.5	12.8	15.6	15.5	15.5	15.0
G	13.45	13.6	13.85	14.1	14.9	14.5	13.3	12.8
H	13.05	14.0	14.5	15.2	15.0	13.6	12.9	11.6
I	13.4	14.1	14.7	15.9	12.05	11.8	10.7	10.5

The data in table VI show that the available moisture was more uniformly distributed, to a depth of eight feet, in the plot which was irrigated at sixty-day intervals than in the plots which were irrigated more frequently.

TABLE VI

Percentage of Available Moisture in Plots A, B, C, and D, Grove 5*

Plot A. 4 acre inches of water applied every 60 days

Depth in ft.	4/23/17	5/2	5/15	5/26	6/4	6/13	6/23	7/6	7/18	7/23	8/1	8/14	8/23	9/5
1st	.64	6.39	5.83	2.52	3.45	−.43	.50	2.31	1.77	.42	−1.33	−.94	−2.73	1.59
2d	7.16	6.18	5.41	7.08	5.25	4.04	7.58	5.03	7.66	7.91	4.48	3.40	1.60	8.48
3d	3.71	6.57	8.71	7.99	8.09	5.59	7.50	8.43	8.73	8.01	4.23	8.05	5.09	9.09
4th	3.65	6.18	6.80	7.86	8.42	7.55	5.82	8.47	8.64	8.05	9.09	9.39	4.72	10.67
5th	....	4.27	....	....	....	....	8.94	8.94	6.35	10.97	9.21	10.84	7.35	9.03
6th	....	3.60	....	....	....	....	8.71	9.31	8.09	9.56	9.81	8.29	6.64	8.63
7th	....	8.34	....	....	....	....	10.32	11.19	10.12	13.96	10.85	7.79	10.41	8.82
8th	....	5.75	....	....	....	....	10.52	12.46	7.26	13.02	10.33	5.37	4.17	8.43

Plot B. 4 acre inches of water applied every 30 days

Depth in ft.	4/23/17	5/2	5/15	5/23	6/4	6/13	6/23	7/6	7/18	7/23	8/1	8/14	8/23	9/5
1st	.97	2.69	4.47	4.14	8.55	.39	.27	4.63	2.05	1.25	−.40	−.45	−2.17	3.17
2d	5.73	3.66	6.96	7.05	10.36	1.09	8.31	6.70	5.12	6.44	5.95	3.95	4.56	7.47
3d	5.79	2.65	6.52	4.50	6.75	5.60	6.86	6.39	5.86	7.39	7.79	4.79	7.00	7.49
4th	5.97	2.78	5.15	6.07	10.23	8.40	11.21	9.56	8.51	9.12	8.59	7.38	7.44	8.86
5th	....	....	....	7.40	....	....	9.38	6.56	7.54	8.75	6.24	6.24	6.70	10.01
6th	....	....	....	4.87	....	....	9.22	8.33	8.57	8.34	3.38	7.92	8.33	11.23
7th	....	....	....	8.50	....	....	10.66	11.98	9.78	9.96	5.49	9.28	7.35	9.64
8th	....	....	....	10.95	....	....	10.10	15.18	8.96	9.20	11.89	7.80	9.70	9.56

*The minus sign indicates soil moisture below the wilting coefficient.

TABLE VI—(*Continued*)*

PLOT C. 2 acre inches of water applied every 30 days

Depth in ft.	4/23/17	5/2	5/15	5/23	6/4	6/13	6/23	7/6	7/18	7/23	8/1	8/14	8/23	9/5
1st	– .75	10.64	3.37	3.05	5.04	2.65	1.19	.83	.34	.55	1.79	–3.87	–2.70	.37
2d	5.05	10 50	3.46	6.80	9.54	5.55	3.85	5.14	4.78	4.41	3.73	.35	.22	4.02
3d	7.10	10.78	2.41	8.01	8.82	5.80	5.72	7.70	6.51	5.28	5.15	2.22	3.41	7.22
4th	6.45	11.31	6.98	9.15	9.51	7.62	7.91	8.01	7.44	6.45	5.67	3.66	4.70	6.94
5th	....	....	....	....	....	....	8.31	6.77	6.55	7.12	8.02	4.98	5.01	6.75
6th	....	....	....	....	....	....	8.63	6.15	6.29	7.80	8.57	4.76	6.88	6.39
7th	....	....	....	....	....	....	8.99	7.14	6.60	8.88	8.77	6.62	8.09	7.67
8th	....	....	....	....	....	....	8.57	4.87	9.09	10.43	9.59	7.72	7.30	9.75

PLOT D. 3 acre inches of water applied every 45 days

Dep h in ft.	4/23/17	5/2	5/15	5/26	6/8	6/18	6/28	7/12	7/23	8/1	8/14	8/27	9/8
1st	2.28	10.20	8.39	5.34	1.58	8.41	5.43	.48	2.67	2.70	–.19	–1.76	– .89
2d	4.55	10.08	8.88	6.14	6.22	10.95	10.60	5.19	7.18	5.71	5.44	– .44	2.35
3d	– .36	7.68	7.68	6.05	7.82	10.53	9.22	8.05	9.05	8.50	6.18	1.06	5.55
4th	6.75	6.34	8.88	8.68	8.36	11.25	9.14	7.68	9.50	9.85	7.04	1.08	6.02
5th	....	....	....	....	....	....	7.91	6.55	9.61	8.32	8.25	3.87	5.52
6th	....	....	....	....	....	....	10.27	5.04	9.17	8.77	10.29	3.77	6.91
7th	....	....	....	....	....	....	10.52	7.79	8.57	8.47	9.35	1.52	7.88
8th	....	....	....	....	....	....	9.92	9.86	9.90	9.37	8.81	2.97	7.75

*The minus sign indicates soil moisture below the wilting coefficient.

The data also indicate that all of the plots probably received more water than was essential for the best development of the trees, since the available moisture in all of the plots was comparatively high throughout the season.

IV. *A comparison of the effect of deep and shallow cultivation on the water-absorbing power of the soil.*

Studies have also been made on the water-absorbing power of heavy soil as influenced by deep and shallow cultivation. The groves studied (6 and 7) are adjacent and the soil is of a heavy type. Each of these groves was irrigated at sixty-day intervals in 1916 and 1917. Grove 6, however, was irrigated from two pipe lines, the upper furrows having a length of 339 feet and the lower ones 300 feet, while grove 7 is provided with but one pipe line at the upper end of the grove and the furrows are 714 feet in length.

After the soil in grove 6 had become sufficiently dry near the surface to prevent puddling, it was harrowed lightly. Later, when the soil had dried out more deeply, a cultivation to a depth of seven to nine inches was given the grove. Usually this latter cultivation was not made until twenty-five or thirty days after an irrigation.[6]

The treatment of the soil in grove 7 was very different from that just described. In this case the soil was cultivated to a depth of three to five inches at a time when portions of it were so wet that puddling resulted. Later two or three cultivations of a similar nature were given before the next irrigation.

The soil in grove 7 did not absorb water as well as the soil in grove 6. This was clearly shown during the winters of 1916–17 and 1917–18, when a portion of the water from the rains ran off and was lost, while the soil in grove 6 absorbed all of the rain water.

Stable manure had been applied to both groves, but on account of the difference in cultivation, it was more thoroughly incorporated with the soil in the grove that was tilled the more deeply. This fact probably influenced the evaporation of the soil moisture and also tended to increase the water-absorbing power of the soil. However, by far the greatest difference in the treatment of these soils was in the manner and depth of cultivation.

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[6] It is necessary to delay the cultivation of this soil much longer than with lighter types. This is due to the fact that being a heavy soil it absorbs much more water than a lighter type, and more time is required for evaporation and percolation to reduce the moisture to a point where the soil can be thoroughly cultivated without injury from puddling.

A comparison of the available moisture (table VII) shows that on May 5, before the first irrigation, the soil in plots A and B, grove 6, which was cultivated more judiciously, contained greater amounts of available moisture than that in plots C and D, grove 7. This difference became greater as the season advanced, until we find that in plot D, grove 7, which received the shallow cultivation, the moisture in the third and fourth feet of soil was below the wilting coefficient continuously after July 5, and the moisture in the first and second feet was below the wilting coefficient a portion of the time. The trees on this plot suffered from a lack of moisture, and the fruit, as well as the leaves of the trees, became wilted. On the other hand, all of the trees in grove 6 were in fine condition and yielded a large amount of good fruit.

The great difference in the physical condition and the moisture content of the soil of these two groves clearly illustrates the need of great care in the cultivation of a heavy type of soil. The soil should not be stirred while it is wet, but should be allowed to remain undisturbed until sufficiently dry to permit thorough and deep cultivation.

CONCLUSIONS.

(1) The results of this investigation indicate that irrigation furrows which exceed 250 or 300 feet in length are undesirable. When furrows of a greater length are used, the soil near the upper end of the furrows must inevitably receive an excess of water. The result is that it becomes "water-logged." A portion of the soluble plant food will be leached and carried below the root zone by the water.

(2) Citrus trees growing on heavy soil may become stunted when excessively irrigated; the leaves turn more or less yellow and many of them fall prematurely. The yield of fruit is also greatly impaired and in some instances the trees may become unprofitable. In many groves it would be advisable to install a greater number of distributing pipe lines in order to shorten the irrigation runs.

(3) In order to secure the best results from the application of irrigation water, it should be applied at the time when it is needed, as gauged by the moisture content of the soil. Whenever this procedure is impracticable, the irrigation water should be applied at intervals best suited to the soil type, as determined by experience or definite experiments.

TABLE VII

PERCENTAGE OF AVAILABLE MOISTURE IN PLOTS A AND B, GROVE 6, AND PLOTS C AND D, GROVE 7*

PLOT A

GROVE 6. Deep cultivation

Depth in ft.	5/5/17	5/14	5/26	6/8	6/25	7/3	7/17	7/24	8/7	8/24	9/4	9/13	9/24	10/4	10/15	10/24
1st	3.00	5.99	7.05	5.71	1.16	−.17	2.36	1.38	1.25	−1.00	−1.25	9.67	5.74	−.96	8.02	5.69
2d	5.60	7.94	7.35	6.82	3.28	1.93	5.05	3.73	2.62	1.36	1.78	2.04	6.45	1.90	2.96	5.47
3d	6.35	6.37	4.64	6.29	5.57	2.89	3.87	6.19	1.58	2.46	−1.01	.49	4.53	2.45	1.77	5.47
4th	11.49	10.13	7.91	11.32	9.20	8.21	10.20	11.35	6.72	7.69	6.59	5.00	8.90	7.59	7.00	7.63

PLOT B

Depth in ft.	5/5/17	5/14	5/26	6/8	6/25	7/3	7/17	7/24	8/7	8/24	9/4	9/13	9/24	10/4	10/15	10/24
1st	.18	9.98	4.86	5.22	3.05	.60	6.15	6.52	1.41	2.00	−.55	9.20	4.69	1.93	1.99	.70
2d	6.03	8.52	6.47	8.34	6.28	4.59	7.37	7.21	3.80	4.45	3.18	10.25	7.50	3.93	3.83	4.26
3d	6.74	6.79	6.99	7.83	7.86	6.32	7.21	7.47	5.03	6.81	4.42	6.87	8.90	7.07	3.53	4.60
4th	4.60	11.40	8.93	9.30	8.29	6.05	8.50	7.89	5.69	6.52	1.25	6.63	7.46	6.52	5.92	5.76

*The minus sign indicates soil moisture below the wilting coefficient.

TABLE VII—(*Continued*)*

PLOT C

GROVE 7. Shallow cultivation

Depth in ft.	5/5/17	5/16	5/26	6/8	6/25	7/5	7/17	7/24	8/7	8/24	9/4	9/15	9/26	10/6	10/15	10/26
1st	−1.63	8.50	5.46	3.24	− .40	−2.48	5.69	4.69	1.13	−2.88	−3.24	7.63	4.77	1.61	7.00	− .92
2d	1.92	7.78	3.54	3.34	3.42	− .03	6.56	5.83	2.54	−1.01	−1.65	5.45	5.08	2.48	5.27	.19
3d	1.52	3.21	−2.07	3.27	2.99	1.30	6.76	2.64	.95	−1.05	−1.21	.99	− .07	.73	.99	.54
4th	2.60	4.12	− .92	2.18	2.13	1.03	7.09	2.31	− .04	− .45	−2.57	2.48	.61	.17	.70	.12

PLOT D

Depth in ft.	5/5/17	5/16	5/26	6/8	6/25	7/5	7/17	7/24	8/7	8/24	9/4	9/15	9/26	10/6	10/15	10/26
1st	−1.98	6.70	3.28	1.39	−2.37	−4.11	.62	−1.61	−4.09	−3.24	−5.53	7.56	2.00	.11	2.62	.15
2d	.24	4.85	1.15	1.20	− .62	−2.04	− .62	−1.21	−2.67	−1.55	−3.27	2.94	1.09	− .60	2.03	.17
3d	−2.60	1.79	−2.02	.30	− .44	−1.71	− .87	−1.41	−1.84	−1.98	−2.97	−1.66	−1.82	−3.30	−3.48	−1.77
4th	−3.60	1.23	−4.32	.22	.18	−2.41	− .39	− .91	−2.31	−2.74	−4.08	− .21	−1.91	−4.34	−4.73	−3.66

*The minus sign indicates soil moisture below the wilting coefficient.

On a heavy loam soil such as that under consideration, the soil moisture was found to remain more uniform and the conditions for root development better, with a sixty-day interval between irrigations, than with a thirty-day interval.

(4) The water-absorbing power of heavy soil is influenced by the method of tillage. The soil should not be stirred while it is wet. Frequent, shallow cultivation tends to pack the soil immediately below the cultivated area. The plow-sole thus formed retards the movement of water in the soil.

Good conditions for plant growth can be obtained by harrowing the soil lightly after it has become sufficiently dry near the surface to prevent puddling; then allowing it to remain undisturbed until it has dried out more deeply so as to permit deep and thorough cultivation.[7]

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[7] The writer wishes to acknowledge his indebtedness to Dr. W. P. Kelley of the Citrus Experiment Station for many valuable suggestions.

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